A proposal for improving muon capture in Geant4

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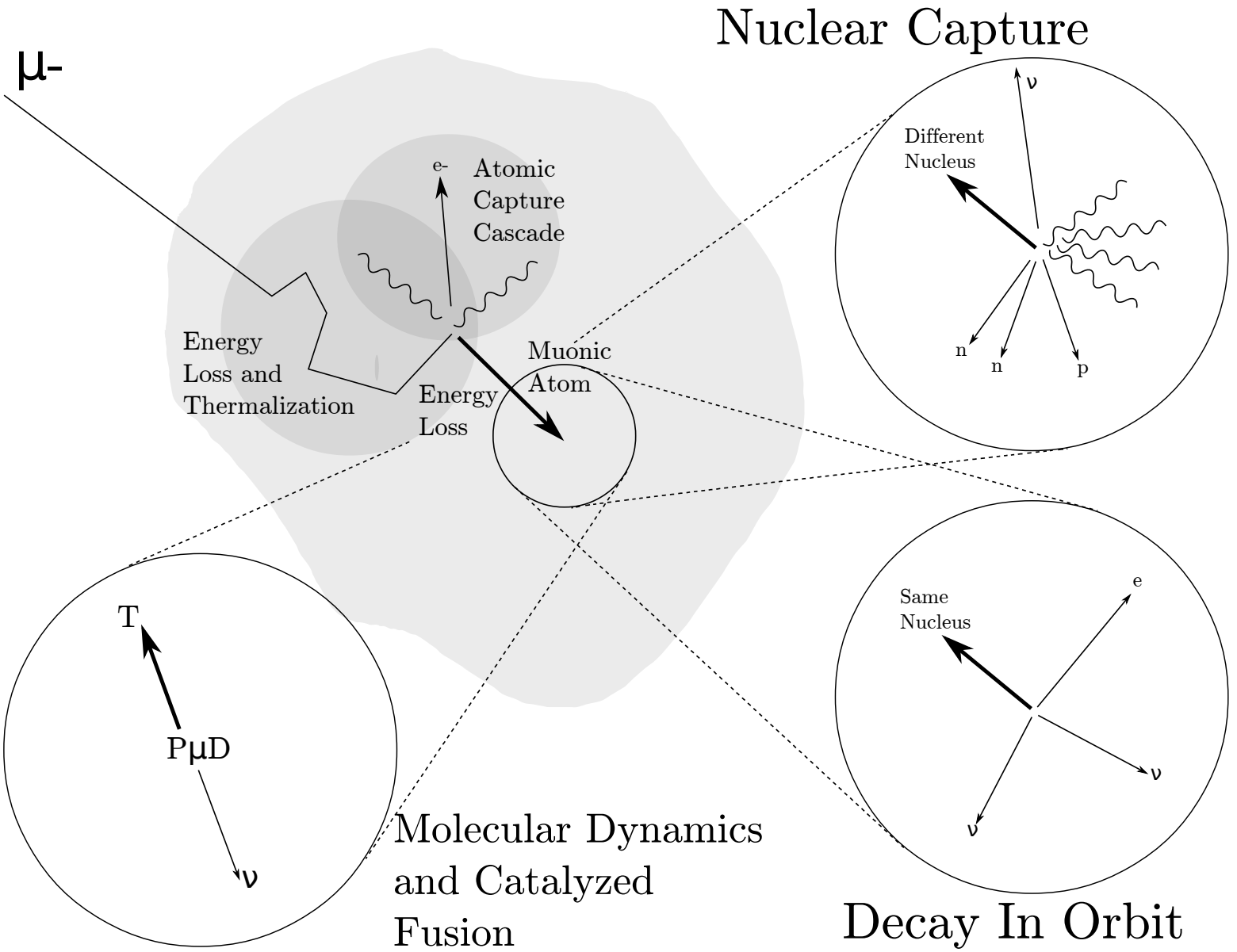
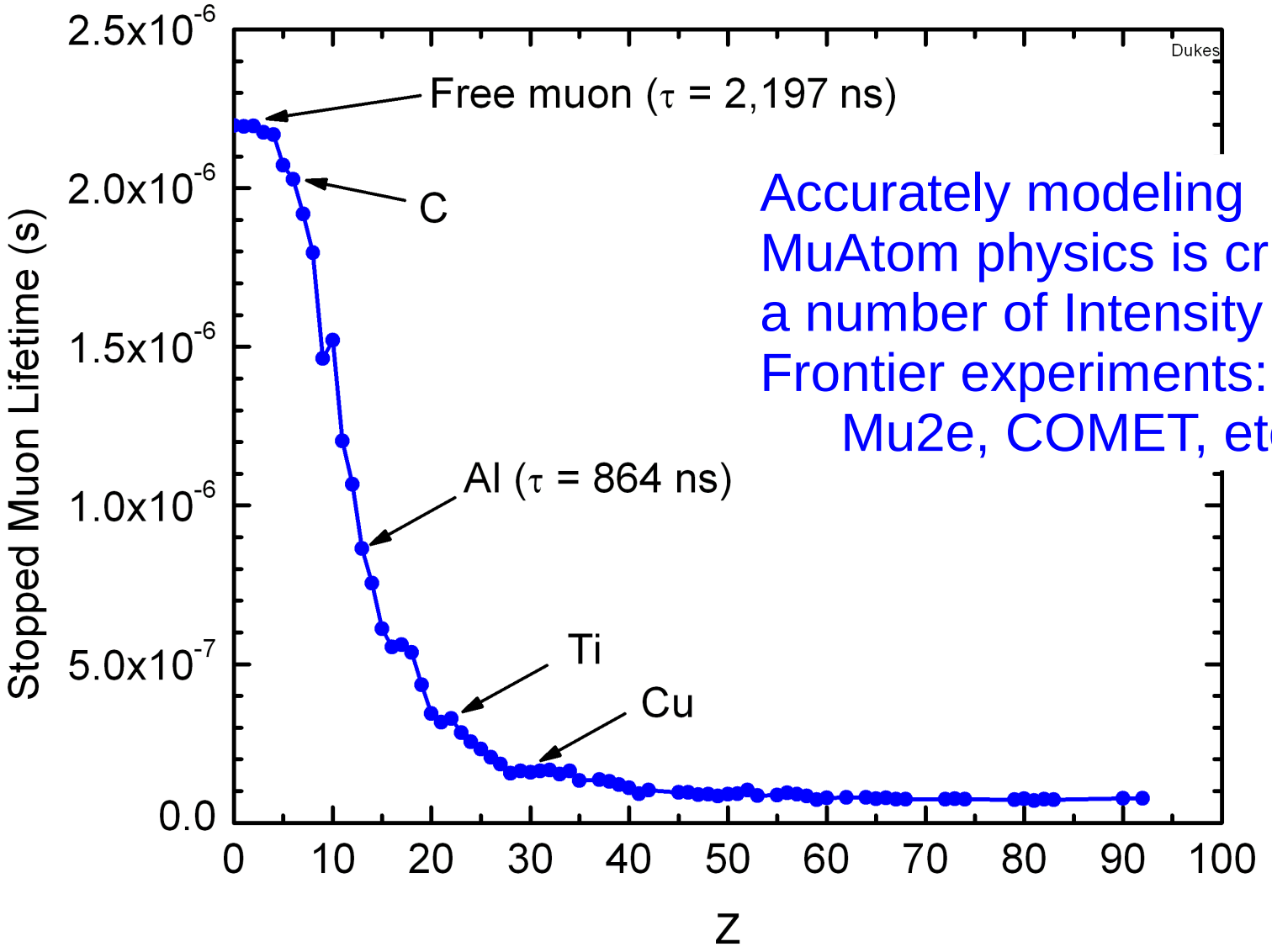
The atomic, nuclear, and particle physics of the μ^- in matter is quite varied



MuAtom physics varies widely with *Z*



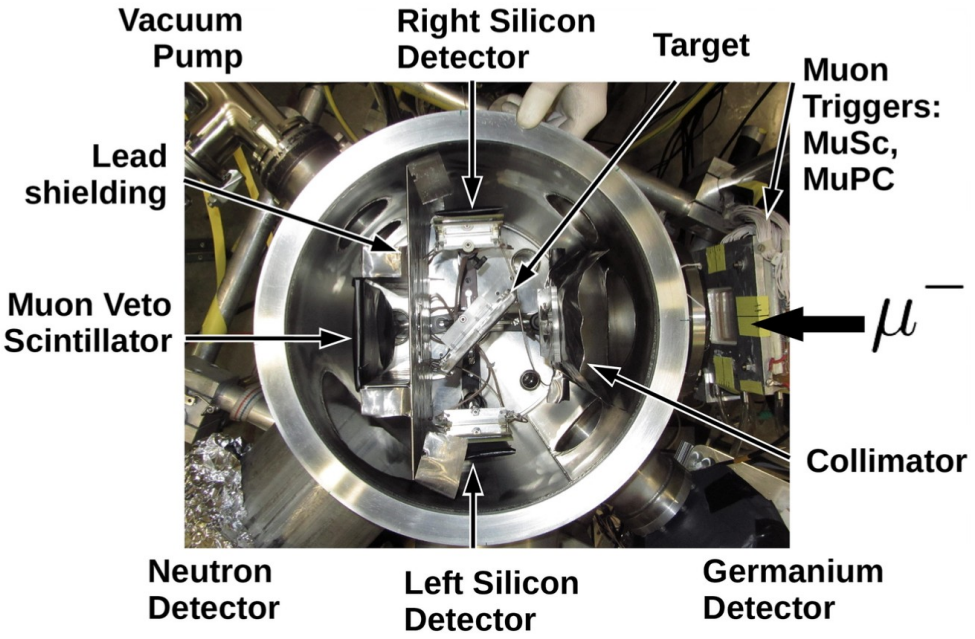
Accurately modeling MuAtom physics is critical to a number of Intensity Frontier experiments:

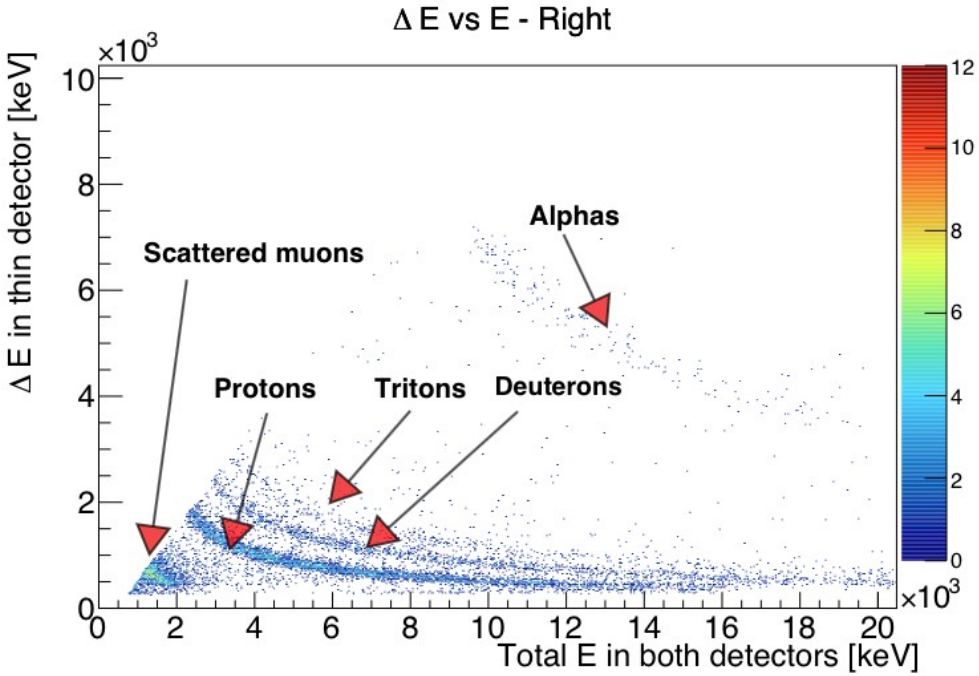
Mu2e, COMET, etc

Current experimental understanding of many aspects of MuAtom physics is not great

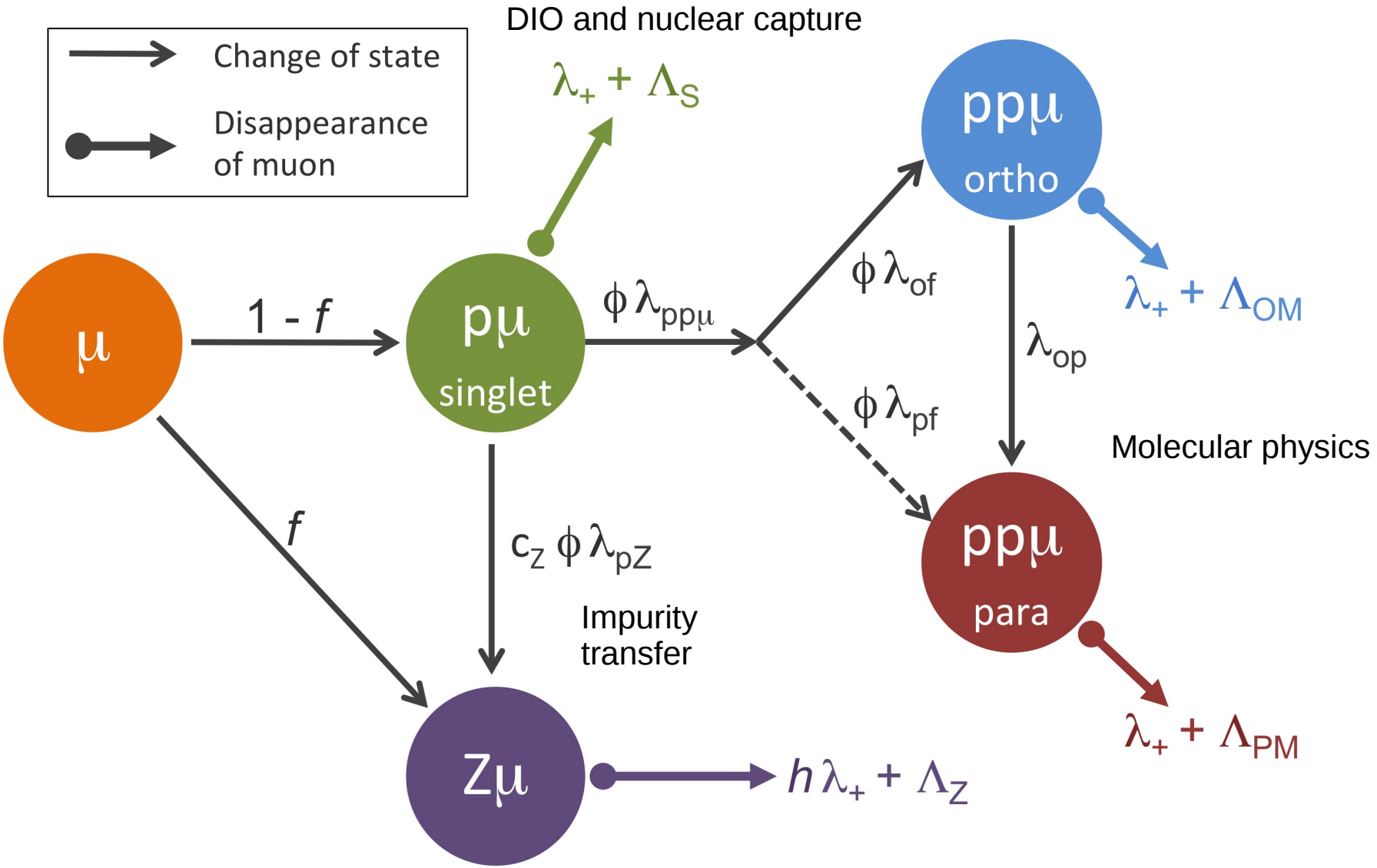
What's the spectrum of secondary particle emission in nuclear capture events?

The situation is so dire that COMET and Mu2e collaborate on AlCap, to study charged particle emission from μAl (μTi...)



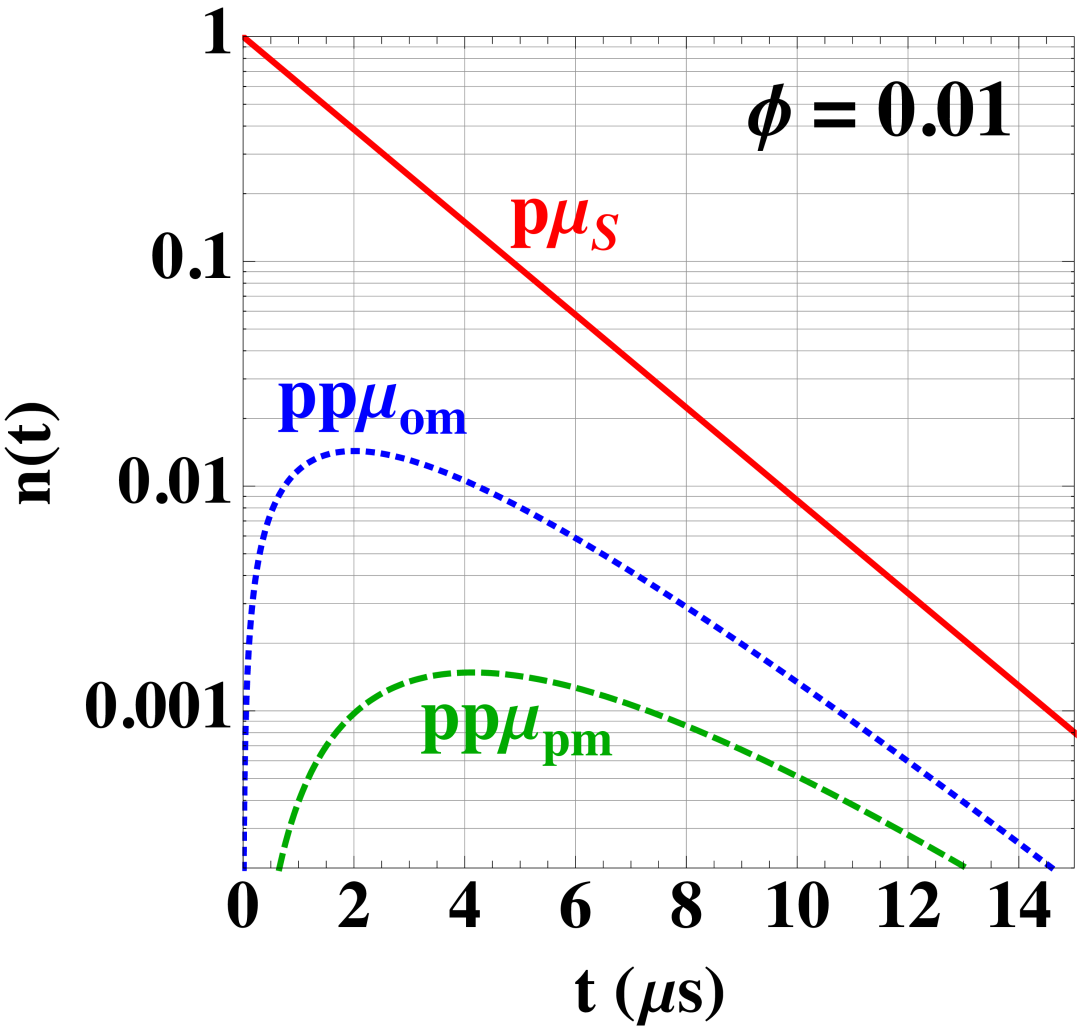


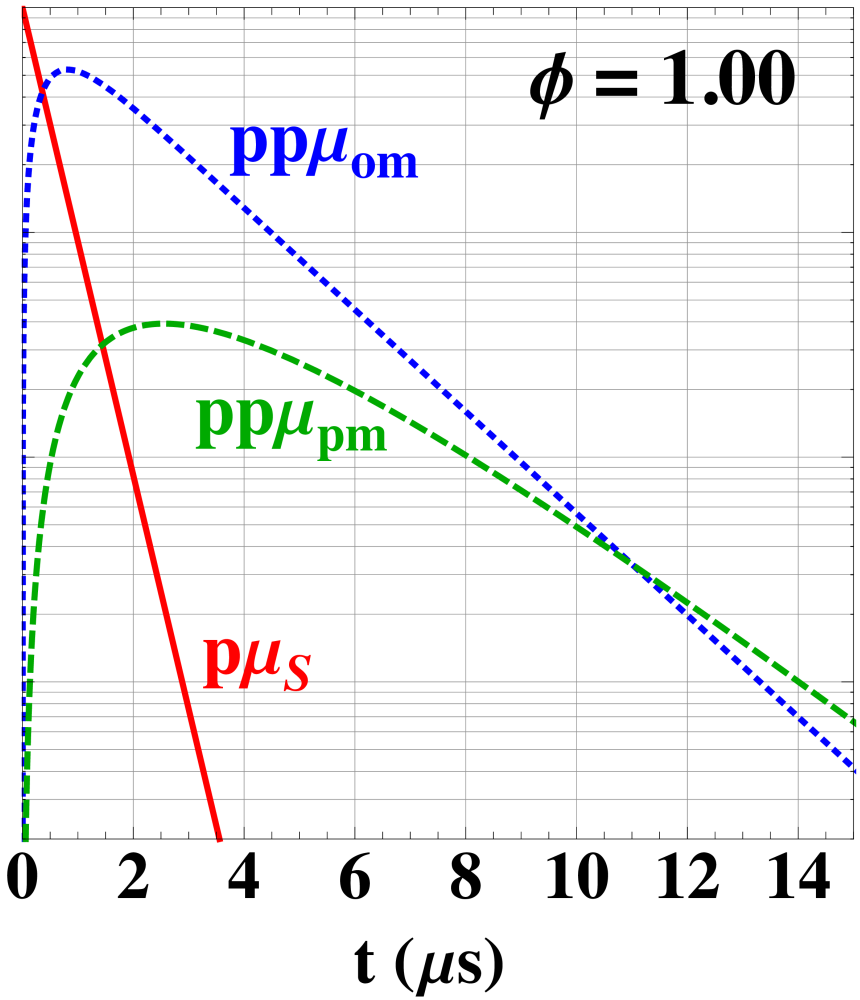
The physics of light muonic atoms is incredibly rich: ^{1}H



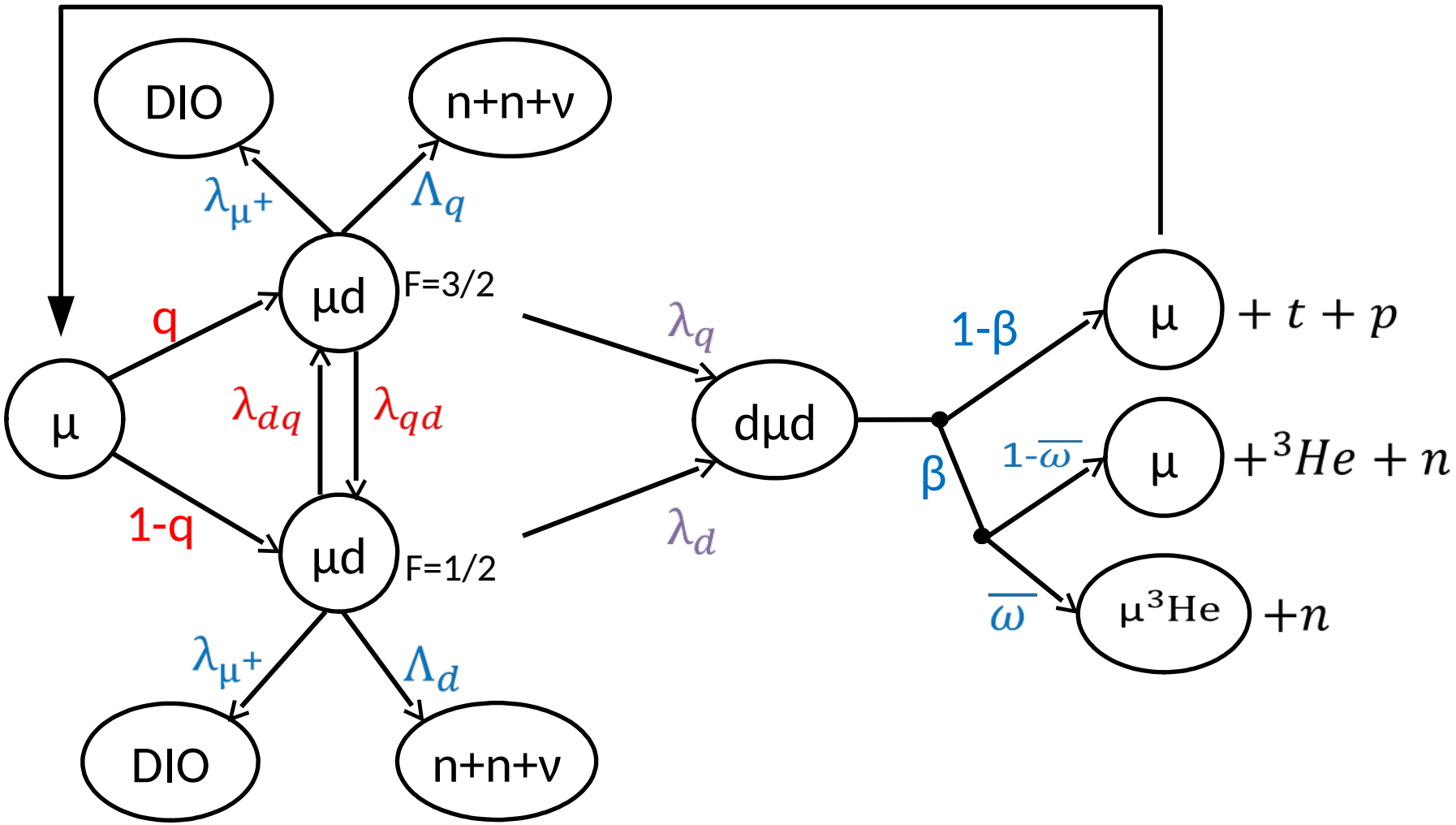
The chemical kinetics are pressure and temperature dependent

Φ is the density





Example kinetics from muon capture on deuterons: ^{2}H



MuSun

MuAtoms can also be transported from the atomic capture location

- Diffusion processes can move muonic atoms non-trivial distance
- Recoil can give non-trivial kinetic energy to light species
- Ramsauer-Townsend effects exist in special cases (deuterons in protium)

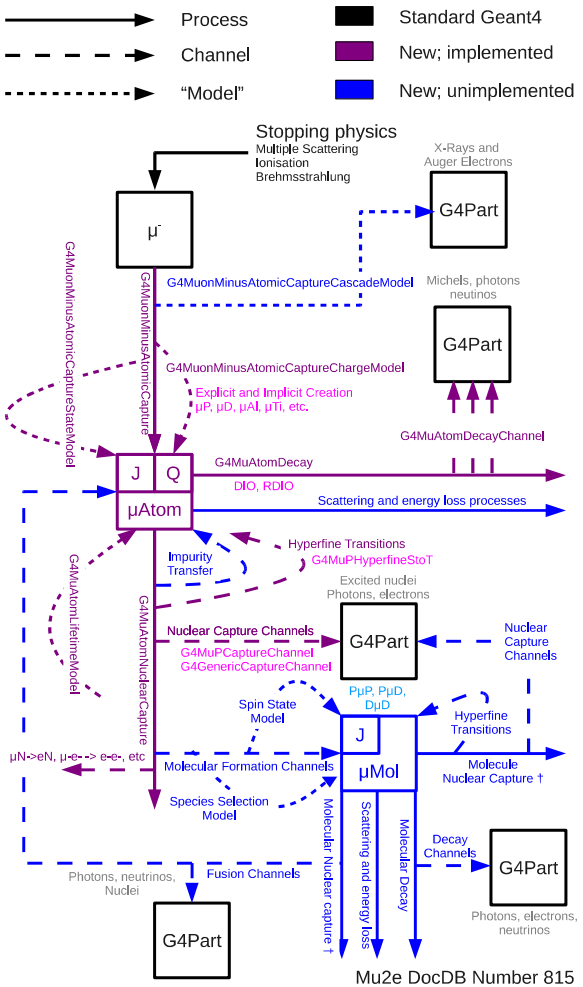
The current implementation of capture at rest works well within its design limits

- class `G4MuonMinusCapture`:
  - A subclass of `G4HadronStoppingProcess`, which performs all steps of the physics:
    - Element selection
    - Atomic capture cascade
    - Nuclear capture or bound decay
  - Attached to `G4MuonMinus`

The current implementation has a few shortcomings that we propose to remedy

- Make the muonic atom a first class particle type
    - Allows transportable muonic atoms
    - Allows to special case the light atoms naturally
    - Muonic molecules are a natural extension
- Factorize the process model
    - Separate atomic cascade, capture, and DIO physics into separate processes that can be customized on a per species basis
        - Radiative extensions can be added as for free radiative muon decays
        - Spin dependent physics can be supported
        - Impurity transfer and catalyzed fusion
    - Provides customization points: add specific model or data driven processes per species

Existing (partial) proof of concept from the 9.5 days, written for MuSun



- Discussion in 2012
- Modifications needed:
  - Hacky mess based on trying to slavishly follow the G4Ions implementation
  - Need a better fit with standard hadronic and electromagnetic physics
  - Changes for the MT world

Schedule

- Fermilab and York/CUNY have proposals to DOE that support work on this
- Assuming you're happy with us pursuing some variant of this...
    - 2016: introduce MuAtoms and factorize the physics processes
    - 2017: introduce light atom physics
    - 2018: radiative corrections (assuming existence of theory calculations)
        - perhaps the molecular physics...

Additional possibilities

- There are other exotic atoms that may benefit from a similar approach
    - Pionic and kaonic atoms
    - Muonium
    - Positronium